Three-Dimensional Modeling of Sediment Trapping and Dispersal on River-Influenced Continental Shelves

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LONG-TERM GOALS

The goal of this project is to quantify the processes that transport sediment in the coastal ocean and subsequently modify the seabed using a combination of numerical and observational techniques. Representations of transport events that can be compared to field observations provide insights that can then be extrapolated to larger temporal and spatial scales.

OBJECTIVES

Many of the processes that transport sediment in coastal seas (wave/current resuspension, wind-, tidal-, and buoyancy-forced currents) are included in a three-dimensional, numerical model that has been applied to the Eel River shelf, northern California (Harris, Geyer and Signell, 2000). This accurately estimates the volume of sediment deposited on the shelf by floods of the Eel River, but predicts deposition on the inner shelf (Figure 1), which is contrary to observations that flood deposition is concentrated off-shore of the 50m isobath (Wheatcroft, *et al.*, 1997). Evidence from the Eel River Shelf shows that sediment concentrations can become high enough (> 10's g/L) in the near-bed region to induce down-slope transport driven by the weight of the suspension (Ogston, *et al*., 2000; Traykovski, *et al.*, 2000). To account for sediment dispersal on energetic, depositional margins, it therefore appears necessary to consider gravity-driven transport of sediment, wave-current resuspension, and plume processes. Dense near-bed layers were not represented in the calculations shown in Figure 1, and models that do include them neglect either the three-dimensionality of the system, or transport processes above the wave-boundary layer (see, e.g. Scully and Friedrichs, in revision). We have incorporated gravitationally-forced transport of a dense near-bed layer into our calculations so that we can compare the relative contributions of this mechanism with wave/current resuspension and plume processes and evaluate whether these three processes can explain observed shelf deposition.

APPROACH

Near-bed observations by Traykovski, *et al.* (2000) indicate that the sediment-laden layer scales in thickness with the wave-boundary layer (~ 5-10 cm). In collaboration with Rocky Geyer and Peter Traykovski (both at Woods Hole Oceanographic Institution), I have therefore added a

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14. ABSTRACT
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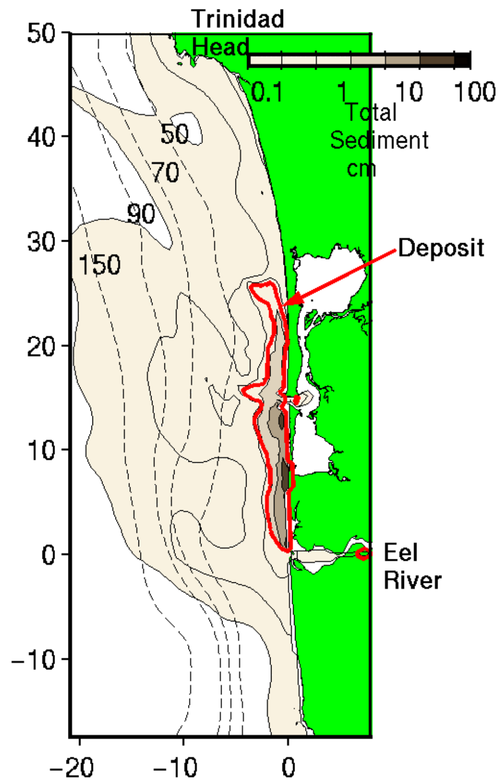

Figure 1: Calculations representing a large flood of the Eel River, northern California in January, 1997. The amount of deposited and suspended sediment predicted 5 days after peak flood. Thickness of total sediment load (suspended and deposited) contoured in brown. Footprint of sediment deposit (>1 cm thick) shown as red line. Predicted volume of deposit agrees with observations, but location does not.

wave-boundary layer component to the coupled three-dimensional hydrodynamic and sediment transport model, ECOM-SED (see Blumberg and Mellor, 1987).

The conceptual framework developed in Traykovski's one-dimensional model is the basis for the new component of the three-dimensional model. It predicts suspended sediment concentrations and fluxes within a sediment-laden layer of the same thickness as the wave boundary layer, and was motivated by observations of a sharp density interface that often appeared at the top of the wave boundary layer. Sediment concentrations within the wave boundary layer (10's g/L) were much higher than in overlying waters, where peak concentrations were ~1 g/L (Traykovski, *et al.*, 2000). At concentrations > 10g/L, the weight of a suspension can induce significant down-slope directed transport. The one-dimensional formulation assumes suspended sediment profiles for the wave boundary layer and near-bed region, and an exchange between the two water layers that scales with the Richardson number at the density interface.

This formulation has been implemented within ECOM-SED by adding a wave-boundary layer to the vertical grid-scheme of the three-dimensional model, and adding sediment advection and limitations on bed sediment availability to Traykovski's wave-boundary layer representation. The thickness of the layer is equal to the wave-boundary layer thickness, and therefore is highest

in the shallowest sites, and decreases offshore. Suspended sediment concentrations and horizontal velocities are predicted for this layer separately from the sediment routines normally included in ECOM-SED. As such, the wave boundary layer component replaces the bottom boundary condition that is imposed in ECOM-SED's sediment transport routines. Sediment is exchanged between the wave boundary layer and the seabed, the overlying water column, and adjacent wave boundary layer grid cells. The sediment exchange rate within the seabed is found following Harris and Wiberg (2001) and is set to be the difference between the deposition rate (settling velocity X concentration), and an entrainment rate equal to the product of settling velocity and Smith and McLean's (1977) reference concentration. Sediment concentration within the wave boundary layer is obtained through a mass-balance that includes horizontal fluxes, sediment flux from the bed, entrainment into, and settling out of the overlying water. The velocity of the sediment/water mixture within the wave boundary layer depends on a balance between the density anomaly of the suspension, and frictional drags between the wave boundary layer, the sea-bed, and the overlying water. Horizontal advection of sediment is carried out using an upwind advection scheme.

WORK COMPLETED

A wave boundary layer grid has been added underneath ECOM-SED's sigma coordinate grid system. The velocities and suspended sediment concentration predicted within this layer are similar to those predicted by Traykovski's one-dimensional model. The model has been implemented for a "sediment reworking case" that examines the ability of gravity-driven flows to drive cross-shelf transport, and for an "inner-shelf mobilization" case that predicts the ability of wave boundary layer transport to remobilize fine-grained sediment deposited in an inner-shelf environment.

RESULTS

Resuspension of fine-grained sediment by energetic waves creates a dense layer of suspended sediment within the wave boundary layer that can significantly increase the cross-shelf transport of sediment (Figure 2). The model was run for a case where unflocculated fine grained sediment (w_s = 0.1 mm/s) is readily available throughout the model domain, waves are energetic (H_{sig} = 3m), and winds are strong and from the south. Sediment concentrations are predicted to be very high, particularly in the inner shelf, and velocities of the wave boundary layer are on the order of 10's of cm/s (Figure 3). The wave-boundary layer velocities calculated for the inner- to mid-shelf region are much higher than the wind-driven cross-shelf currents, as are sediment fluxes (Figure 2). The flux predicted within the wave boundary layer for these conditions (4 kg/m s) could deliver a 5 cm thick by 5 km wide flood layer to the mid-shelf region within 14 hours.

Sedimentation patterns are dominated by removal of sediment from the near-shore region, and deposition just off-shore. Advection of wave-boundary layer sediment enhances the deposition off-shelf, whereas the erosion is dominated by entrainment into the wave boundary layer and overlying water column. The main limitation on this process appears to be the availability of suspendable sediment. Limiting the amount of available fine-grained sediment enlarges the near-shore erosional area, and moves the depositional area towards deeper water.

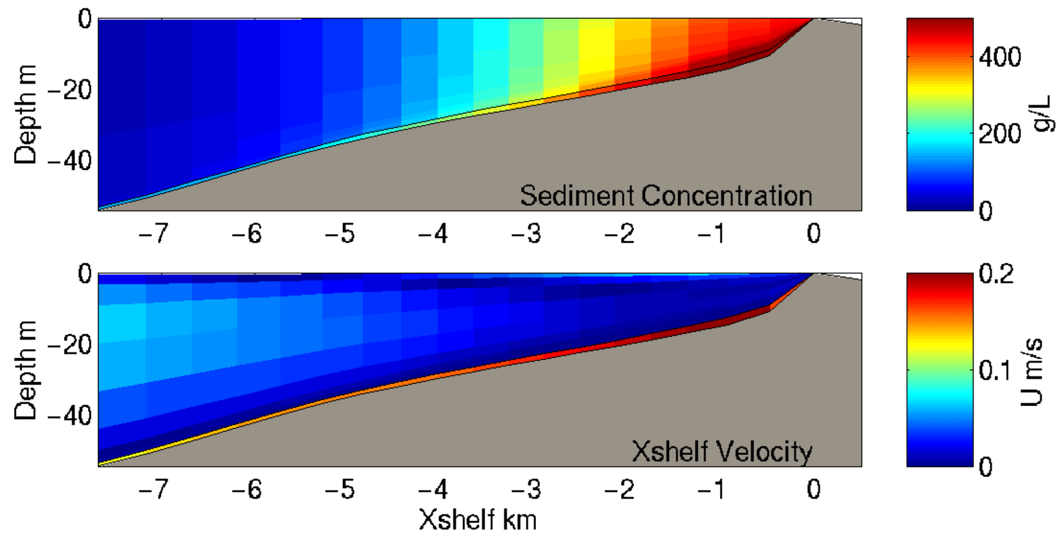

Figure 2: Calculations for a transect located between Eel River mouth and Humboldt Bay, assuming strong winds from the south and energetic waves. Values for wave boundary layer shown in layer near bed; thickness of wave boundary layer doubled for this plot. The high winds and low settling velocity used enable large concentrations of sediment to be entrained from the wave boundary layer into overlying water.

IMPACT/APPLICATIONS

Further enhancement of this model promises to improve our ability to represent sediment transport in coastal seas by better representing the near-bed flow and sediment fields that are critical to sediment transport. Additionally, gravitational forcing created by dense suspensions in the wave boundary layer appears to be a dominant cross-shelf transport mechanism. Further refinement of this numerical model will provide a tool for assessing the relative significance of this cross-shelf transport mechanism compared to wave-current resuspension and transport. The formulation was completed within one subroutine that was added to ECOM-SED, and as such can be ported to other numerical models.

TRANSITIONS

Our calculations of suspended sediment concentrations in the freshwater plume have been shared with other members of the STRATAFORM research team, and will be included in the forthcoming STRATAFORM master volume. We have additionally provided predictions of suspended sediment concentrations to Paul Hill (Dalhousie University).

RELATED PROJECTS

I have continued to use a two-dimensional sediment transport model formulated for the continental shelf to gain insight on the ability of wave-current suspension to modify the seabed. This effort was motivated by the Office of Naval Research's Geology and Geophysics Program,

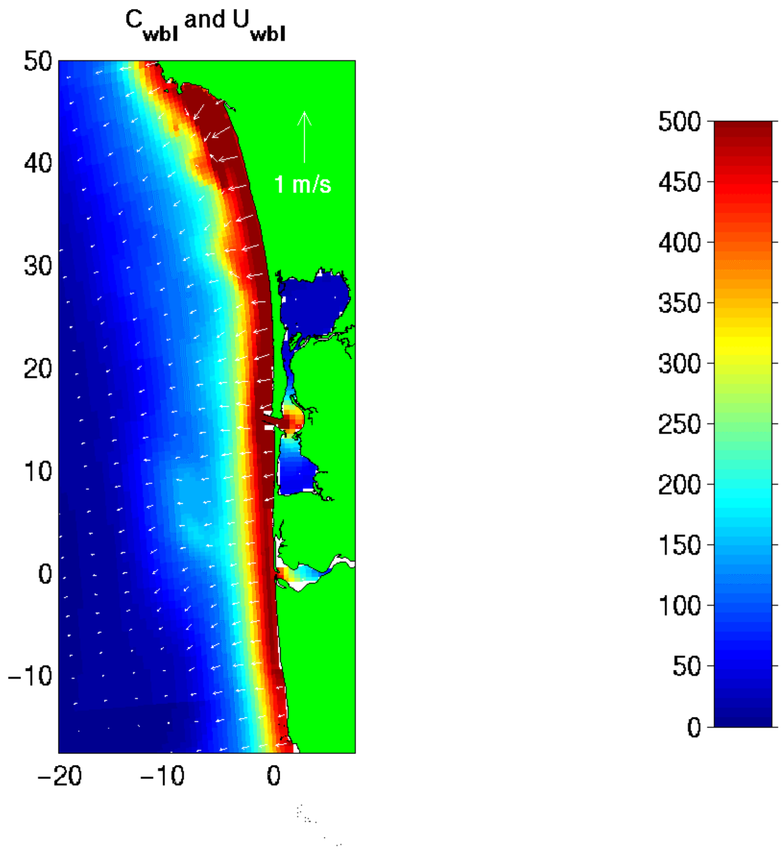

Figure 3: Predicted concentration of sediment (C_{wbl}) and velocity (U_{wbl}) in the wave boundary layer for energetic waves (H_{sig} = 3m), unflocculated sediment, and strong winds from the south. Color represents C_{wbl} (g/L); white arrows represent U_{wbl}.

with additional support from the US Geological Survey. Results from this fiscal year include a publication that evaluates the ability of wave-current resuspension to modify sediment texture on steep continental shelves (Harris and Wiberg, in press). I also collaborated with Pat Wiberg (University of Virginia), and Dave Drake (Drake Marine Consulting) to improve model predictions of modifications to seabed texture, by enhancing the model's treatment of bioturbation and bed cohesion. The model predictions were improved, as compared to textural observations made on the Eel River Shelf (Drake, 2000), but the results implied an inner-shelf source of fine-grained sediments during non-flood storms.

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